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ABSTRACT

The U.S. Environmental Protection Agency (EPA) is studying the effectiveness of various ways to reduce high concentrations of radon in houses. This booklet was produced to share what has been learned with those whose radon problems demand immediate action. The booklet describes nine methods that have been tested successfully--by EPA and/or other research groups--on houses with high indoor radon levels. The information presented here is concerned primarily with radon which enters a house from the underlying soil. The first lesson to learn about radon reduction is this: No two houses are alike. Even houses that look the same have small differences in construction that can affect radon entry and the design and effectiveness of reduction techniques. Underlying soils also may vary, even among houses which sit close together. This booklet is intended primarily for homeowners who already have had their homes tested for radon and have decided that they need to take some action to reduce radon levels. (CW)

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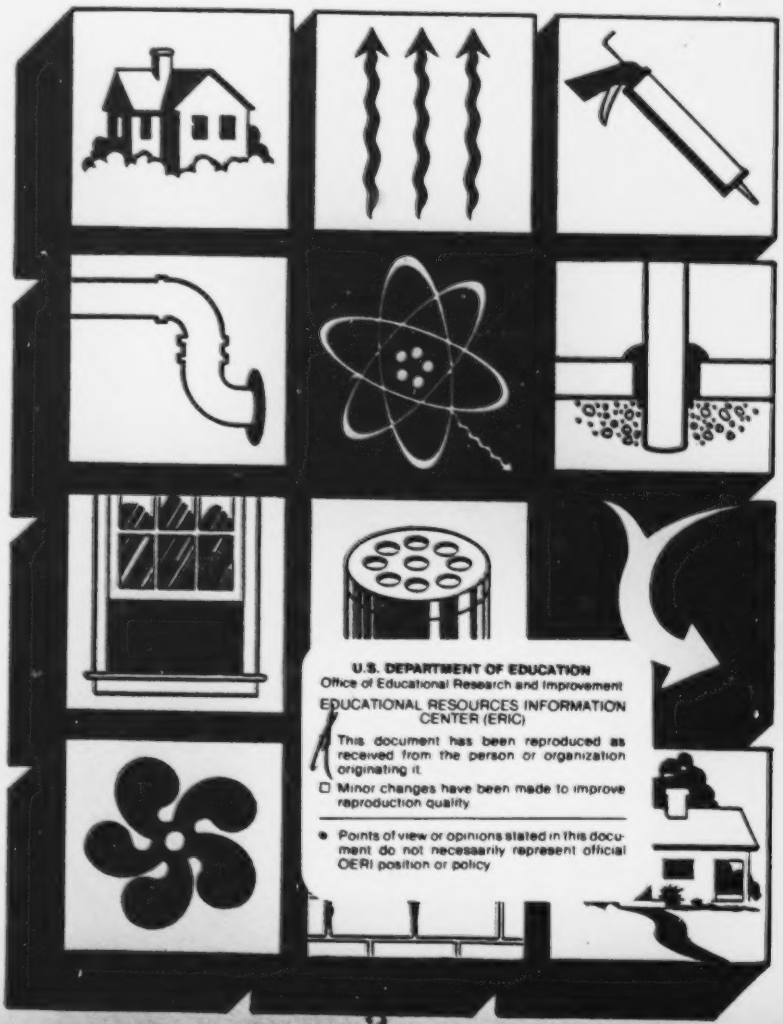
Research and Development

EPA

Radon Reduction Methods

A Homeowner's Guide



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EPA Study

The U.S. Environmental Protection Agency (EPA) is studying the effectiveness of various ways to reduce high concentrations of radon in houses. While our work is far from complete, we have gained some information which may be of immediate use to homeowners. We are publishing this booklet to share what we have learned with those whose radon problems demand immediate action. The booklet describes methods that have been tested successfully—by EPA and/or other research groups—on houses with high indoor radon levels. The information presented here is concerned primarily with radon which enters a house from the underlying soil. Additional information will be published as it becomes available.

Unique Problems

The first lesson to learn about radon reduction is this: No two houses are alike. Even houses that look the same have small differences in construction that can affect radon entry and the design and effectiveness of reduction techniques. Underlying soils also may vary, even among houses which sit close together. These differences can affect the results obtained from using the radon-reduction methods described here.

General Information

This booklet is intended primarily for homeowners who already have had their homes tested for radon and have decided that they need to take some action to reduce radon levels. If you are uncertain of the meaning of such test results, or if you need general information about radon in houses, read the EPA leaflet, *A Citizen's Guide to Radon: What It Is And What To Do About It*. To get a copy, contact your state radiation protection office. If you have difficulty locating this office, you may call your EPA regional office (see list at the end of this booklet) to obtain the appropriate address and telephone number.

Using Contractors

Most radon remedies require the skilled services of a professional contractor who is experienced in radon-reduction procedures. (EPA and the states are currently working to increase the number of experienced contractors.) Due to the skills required, do-it-yourself efforts are not recommended, and this booklet does not attempt to give the homeowner detailed instructions for corrective action. But, the information here should

help you make informed decisions on what type of remedy is needed, and may assist you in evaluating proposals from contractors.

We cannot overemphasize the importance of carefully selecting a contractor and reviewing any proposal for radon-reduction work at your house. Asking for business references and checking with your local Better Business Bureau or Chamber of Commerce will help you ensure that a contractor is qualified. Getting a second opinion from another contractor or from one of your state's radiological health officials can help you decide if a proposal is reasonable. You should be certain to get a written estimate of costs which stipulates the work to be done. Because radon reduction work is so new, contractors generally will be unable to *guarantee* a reduction in radon levels. In fact, promises of great results should be viewed with some scepticism.

Technical Information

Those homeowners who are confident they have the tools, equipment, and skills to do the job themselves may want to read EPA's more detailed manual, *Radon Reduction Techniques for Detached Houses* (EPA/625/5-86/019). To get a copy write:

U.S.EPA
Center for Environmental Research Information
26 West St. Clair Street
Cincinnati, Ohio 45268

Methods

This booklet describes various methods which may reduce the level of radon in your house—either by preventing its entry or by replacing contaminated indoor air. Some of the methods are simple, some are complex, some are much more expensive than others.

The effectiveness of any one method will depend upon the unique characteristics of each house, the level of radon, the routes of radon entry, and how thoroughly a job is done. No one can guarantee that these methods will work as they did in the test houses.

Sometimes, a single method may be sufficient, but often—especially where levels are high—**several methods will need to be combined to achieve acceptable results.**

Follow-up

Once an action (or combination of actions) has been performed, it is important that you have further testing done. If the radon levels have not been satisfactorily lowered, other steps may be

taken, and the testing process repeated. All tests should be performed in exactly the same manner as the test which confirmed the high radon levels in your house.

Due to the many factors affecting the performance of any reduction technique, a trial-and-error approach usually will be necessary to achieve lasting radon reductions.

Other Concerns

Avoiding Depressurization

An important factor in determining the rate at which radon enters your home is the difference between the air pressure indoors and the air pressure in the soil. When the air pressure indoors is less than the gas pressure in the surrounding soil, radon can be drawn through cracks and openings into your house. Lowered air pressure in your house can be caused by several factors, including: windows open only on the downwind side of the house, exhaust fans such as those in your kitchen or attic, and consumption of air by appliances such as furnaces and clothes dryers.

Air Cleaners

Air cleaners are devices that filter particles—such as dust—from the air. Existing information does not clearly document the effectiveness of air cleaners in reducing the risk of developing lung cancer from exposure to indoor radon. EPA and other groups are currently gathering information to make this determination. Until more is known, EPA believes that the data do not warrant discontinuing the use of air cleaners already installed, nor can we suggest installing air cleaners to reduce your risk.

Radon in Water

Radon in water can be released into the air when the water is agitated, aerated, or heated. However, the level of radon in household water must be very high to influence the overall level in the air within a house.

In some cases, water from private wells or small community wells does contain sufficient radon to contribute significantly to elevated levels within a house. Water coming from large community water supplies releases most of its radon before it reaches individual houses.

For more information concerning radon in water, contact your state radiation protection office.

Method	**Natural Ventilation**
How It Works	Replaces radon-laden indoor air with outdoor air. Some natural ventilation occurs in every house as air is drawn through tiny cracks and openings by temperature and pressure differences between indoor and outdoor air. In the average American house, all the interior air is replaced by outside air about once every hour. In technical terms, this is called 1.0 ach (air changes per hour). Newer houses, which are generally "tighter," may have air-exchange rates as low as 0.1 ach (one-tenth that of the average house). The rate in older houses, on the other hand, may be twice the average (2.0 ach).
Cost	There are no installation costs unless devices must be purchased to hold windows or vents in an open position, or to detect or prevent unauthorized entry through these openings. Use of natural ventilation in cold weather will increase your heating costs substantially, however. For example, if you were to increase the air exchange rate to eight times its normal level in your basement and still maintain comfortable temperatures there, your annual house heating bill could be as much as three-and-one-half times greater than normal. If you normally run an air conditioner in hot weather, cooling costs will be similarly greater.
Reductions	Tightly constructed houses with low air-exchange rates are likely to benefit more from ventilation increases than are houses with naturally high exchange rates. Radon reductions as high as 90 percent can be achieved using ventilation to increase the exchange rate in a "tight" house from 0.25 ach to 2.0 ach. Ventilation can only do so much, however. There is a point at which increasing ventilation will have no further significant effect on radon levels in the house.
Limitations	While natural ventilation can be tried easily enough in most houses, it probably will not sufficiently lower radon levels that are above 0.2 WL (40 pCi/l).* Also, for much of the year, in most

*WL (Working Levels) and pCi/l (picocuries per liter) are two commonly used measurement units for radon.

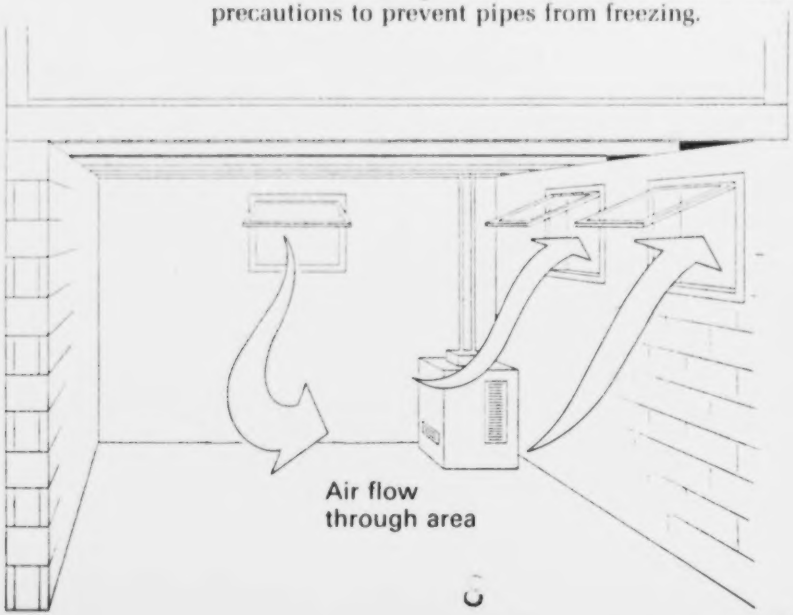
of the country, the trade-off in decreased comfort and/or excessive heating or cooling costs may prove unacceptable. Shifts in the force and direction of the wind will make it nearly impossible to maintain a constant air exchange rate over time.

Procedure

You should ventilate the lowest level of your house, where it is in direct contact with the primary source of radon: the soil. If you have a basement or crawl space, that is the area to ventilate. (If you ventilate your basement, you may find it more economical or comfortable to close it off and limit its use.) If your house sits on a concrete slab, then your only choice is to ventilate the living area. Opening windows around **all** levels of your house (including the main living area) is recommended whenever outdoor conditions permit.

As noted earlier, radon is drawn into your house when the air pressure in the basement or lowest level is less than the air pressure in the surrounding soil. Therefore, it is imperative that any ventilation system does not further reduce the air pressure within your house and increase this "pull." To guard against this, be certain to open vents or windows equally on all sides of the house. Also, minimize the use of exhaust fans.

When ventilating unheated areas, be sure to take precautions to prevent pipes from freezing.



Method	**Forced Ventilation**
How It Works	Replaces radon-laden indoor air with outdoor air. Uses fans to maintain a desired air-exchange rate independent of weather conditions. (Much of the information in the preceding section on "Natural Ventilation" is applicable to "Forced Ventilation" as well.)
Installation	When using forced ventilation, the flow of air between entry and exhaust points must be properly balanced. Otherwise, additional radon could be drawn in, or moist air could be forced into the walls or attic, where it can cause structural damage. Therefore, we suggest that design, installation, and testing be done by competent and experienced contractors.
Cost	The total cost of fans with the air-moving capacity to meet typical needs should be no more than $150. The cost of electricity to operate the fans could be as much as $100 per year. Use of forced ventilation throughout cold weather will substantially increase your heating costs. If, for example, you were to increase the air exchange rate to eight times its normal level in your basement while maintaining comfortable temperatures there, your annual house heating bill could be as much as three-and-one-half times greater than normal. If you normally have an air conditioner running in hot weather, your cooling costs will be similarly greater.
Reductions	As pointed out in the preceding section, "tight" houses with low air-exchange rates are likely to benefit more from ventilation increases than are houses with high exchange rates. Depending upon the amount of radon entering your house, there will be some level below which increased ventilation will cease to be effective.

Limitations

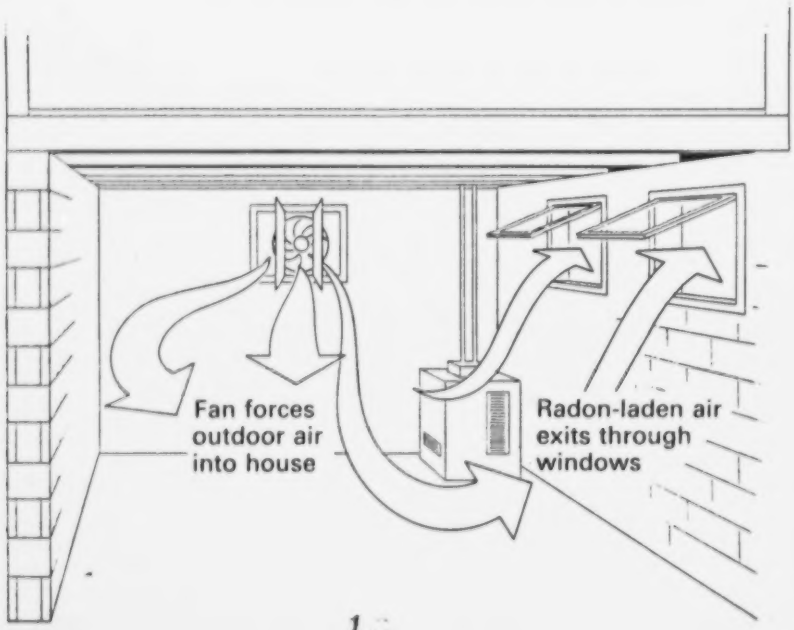
Forced ventilation, like natural ventilation, can be employed in most houses, but, by itself, is unlikely to provide sufficient reductions of radon levels that are above 0.2 WL (40 pCi/l). And, in many cases, the trade-off in decreased comfort and/or excessive heating or cooling costs may prove unacceptable.

Procedure

You should ventilate the lowest level of your house. (Closing off and not using a basement may be advisable.) Ventilating all levels is recommended whenever outdoor conditions permit. Air should be blown **into** the house and allowed to exit through windows or vents on adjacent or opposite sides. The use of an exhaust fan to pull air out of the house may decrease the interior air pressure and draw more radon inside.

Air distribution and ventilation rate can be controlled by the sizing and location of fans and the use of louvered air deflectors. EPA's experience suggests that you should install two or three fans rated at twice the air moving capacity calculated to be needed for the desired increase in ventilation.

When ventilating unheated areas, be sure to take precautions to prevent pipes from freezing.

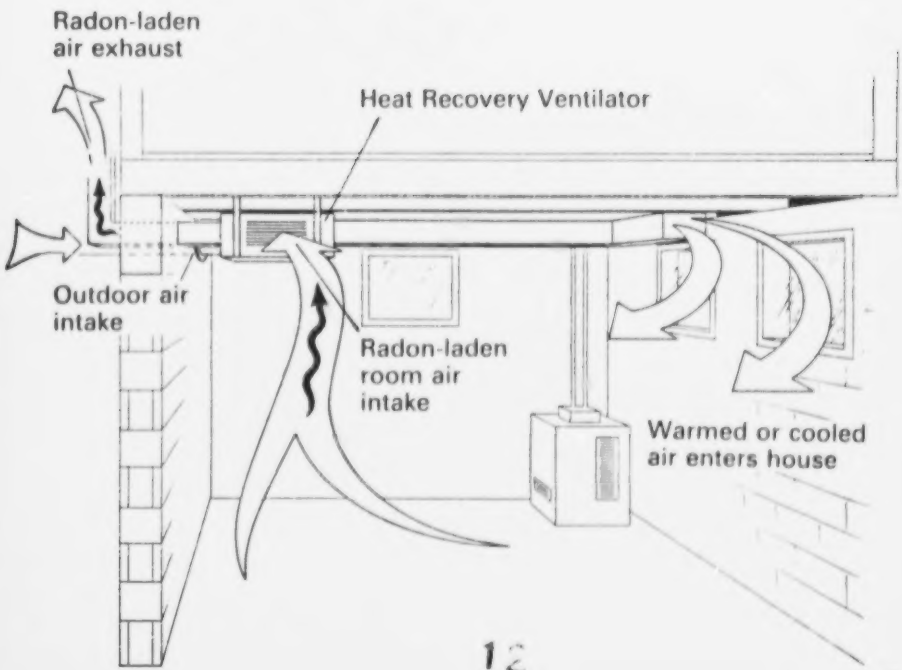


Method	**Heat-Recovery Ventilation**
How It Works	Replaces radon-laden indoor air with outdoor air. A device called a "heat recovery ventilator" (sometimes referred to as an "air-to-air heat exchanger") uses the heat in the air being exhausted to warm the incoming air. In an air-conditioned house in warm weather, the process is reversed: the air being exhausted is used to cool the incoming air. This saves up to 70 percent of the warmth (or coolness) that would be lost in an equivalent ventilation system without the device.
Installation	Requires installation and testing by competent, experienced professionals.
Cost	Installation costs (materials and labor) will range from $400 to $1500, depending on the size of the unit needed. The cost for electricity to operate the equipment could be as much as $100 per year. Use of a heat recovery ventilator in your basement could increase your heating bill as much as 40 percent, depending upon your need to replace the heat that is lost.
Reductions	Heat-recovery ventilation, by itself, is not likely to provide sufficient reductions of radon levels that are above 0.2 WL (40 pCi/l). In some houses, heat recovery ventilators in the basement have been used to reduce radon levels by up to 96 percent.
Limitations	Heat recovery ventilators can be installed in any type of house, but are generally not used in crawl spaces. Replacing the heating or cooling energy lost (at least 30 percent) can be costly.

Procedure

To effectively reduce high radon concentrations a house-sized heat exchanger should probably be run continuously (in the basement, if you have one). The precise location and configuration of the ventilation ductwork will depend upon the type of heating and ventilation you have now, and the source and entry points of the radon.

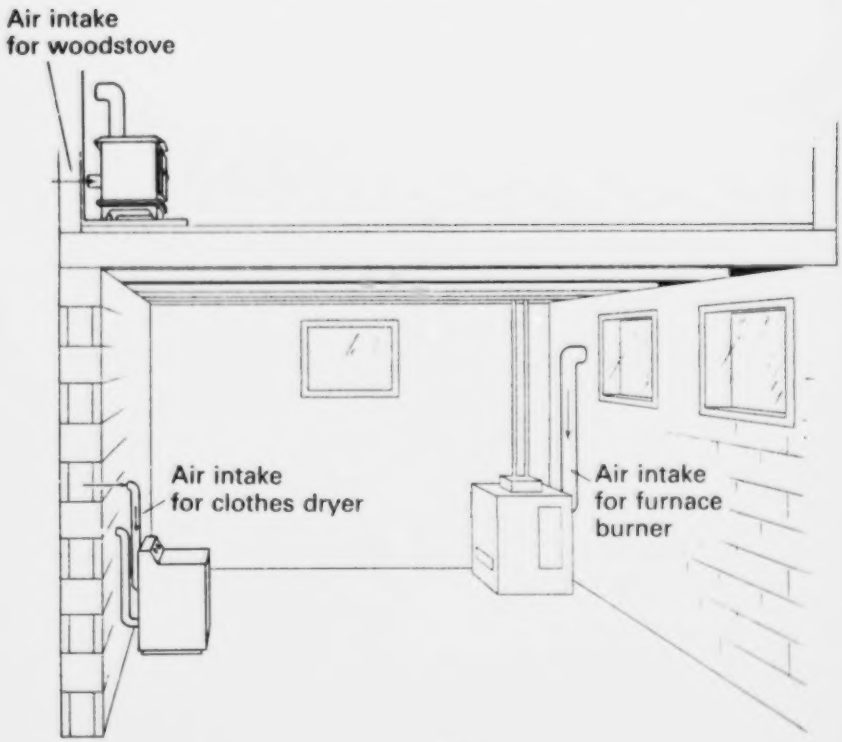
For lower radon concentrations, a window-sized unit may be enough. In which case, replacing the lost heating or cooling energy would be less costly.



Method	Air Supply
How It Works	Reduces the amount of radon drawn into your house. Some home appliances or features—such as your furnace, clothes dryer, and fireplace—lower the air pressure in your house by consuming air and/or exhausting it to the outside. The lower the air pressure in your house, the more radon-laden air will be drawn inside from the underlying soil. While there are several other causes of low indoor-air pressure, providing appliances with separate sources of external air can reduce the amount of radon entering the house.
Installation	We recommend that you use the services of a contractor with the knowledge and experience to determine the amount of air needed for appliances to function properly and safely.
Cost	Installation costs will vary greatly depending upon the type and location of the appliances. For some appliances, there may be a slight increase in operating cost due to the lower temperature of the air being heated.
Reductions	Because each situation is different, it is impossible to predict the reduction in radon levels that can be expected as a result of supplying appliances with sources of outside air. Results will depend upon the operating condition of the appliance, the source of the radon, and other conditions within your house at any given time.
Limitations	The usefulness of supplying outside air to appliances is mostly limited to increasing the effectiveness of other methods. For example, if a block-wall suction system (*see page 18*) functions less effectively in the winter, the problem could be that the draft caused by a fireplace or woodstove is overpowering the system.

Procedure

Ductwork or piping can be run from any suitable exterior wall to the appliance. The appliance's normal vents or inlets for room air must be sealed shut. A manual or automatic damper should be placed in the ductwork to prevent entry of cold air when the appliance is not in operation. The outside end of the ductwork should be screened to prevent entry of debris, insects, etc.



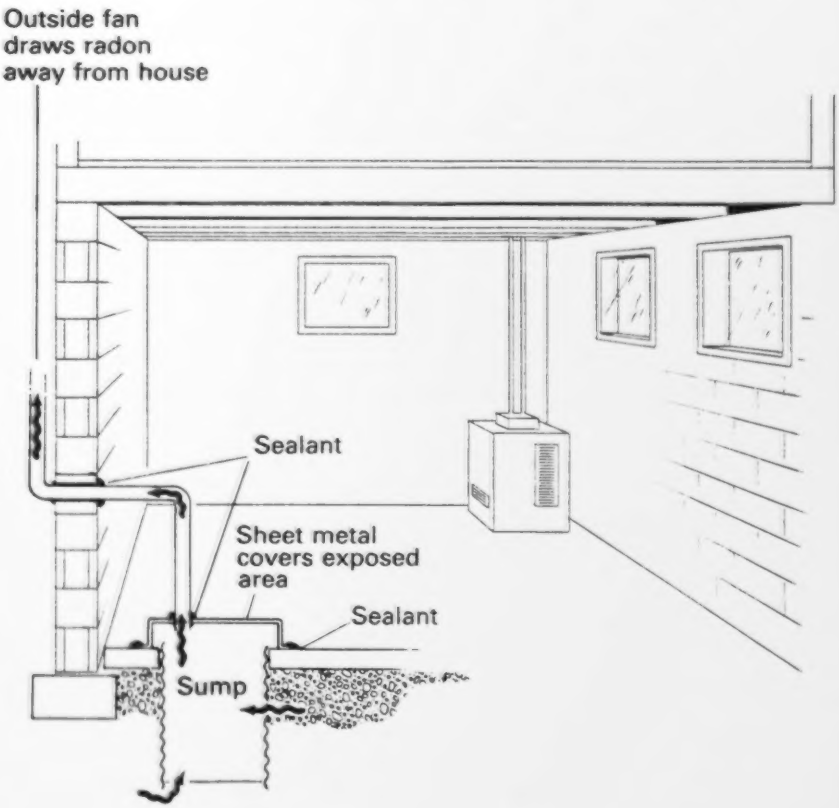
Method	**Covering Exposed Earth**
How It Works	Reduces the flow of radon into the house. Exposed earth—in basement cold rooms, storage areas, drain areas, sumps, and the like, as well as in crawl spaces—is often a major entry point for radon.
Installation	Requires installation by competent, experienced contractors or highly skilled homeowners.
Cost	Covering or sealing small areas (and ventilating covered air spaces as necessary) often costs under $100. The annual costs for operating small exhaust fans, should they be needed, is minimal.
Reductions	Since radon can seep through any small opening, the degree of radon reduction achieved by sealing any particular area cannot be predicted. Effectively blocking a major entry point, however, should result in significant reductions of the overall radon level in your house. In houses with marginal radon problems, covering exposed earth, along with sealing cracks and openings (see page 14) may be a sufficient remedy. Covering exposed earth is also likely to enhance the effectiveness of most other radon-reduction methods, such as block-wall ventilation and sub-slab suction.
Limitations	As a house settles and reacts to external and internal stresses, covered areas can open again Therefore, periodic checking and maintenance are required.

Procedure

Any basement earthen floor should be excavated as necessary and a poured concrete floor installed. Small areas may be capped with an impermeable covering such as aluminum sheet metal. All joints must be carefully sealed. When the covering encloses an air space, such as that around a sump pump, a small fan should be installed to exhaust the air to the outside.

A crawl space connected to a basement can be covered, ventilated, and/or sealed off from the basement.

A crawl space not connected to a basement can be ventilated (as discussed in the section on natural ventilation) or the earthen floor can either be covered with a gas-proof liner (with passive vents to the outside) or covered with concrete.



Method	Sealing Cracks and Openings
How It Works	Reduces the flow of radon into the house. Radon is a gas that can pass through any opening in a floor or wall which touches the soil, and enter your house through openings around utility pipes, joints between basement floors and walls, the holes in the top row of concrete blocks, and tiny cracks and openings (such as the pores in concrete block) not easily seen by the human eye. Sealing such cracks and openings is often an important preliminary step when other methods are used. For houses with marginal radon problems, sealing alone may be sufficient. In some houses, certain areas will be difficult, if not impossible, to seal without significant expense. These include: the top of block walls, the space between block walls and exterior brick veneer, and openings concealed by masonry fireplaces and chimneys.
Installation	Since effective sealing generally requires meticulous surface preparation and carefully controlled application of appropriate substances, the work should only be done by experienced and competent contractors or highly skilled homeowners.
Cost	Cost of materials is generally minimal. The amount of labor involved can vary widely depending upon the number of routes to be sealed and their accessibility. Most jobs can be done for $300 to $500.
Reductions	When sealing is used alone, you should expect only low to moderate reductions in radon levels. If sealing is done thoroughly—and all exposed earth is covered—reductions may be sufficient in some houses. Sealing is required for block-wall ventilation and sub-slab suction to work effectively (see pages 18 and 20).

Limitations

It is very difficult to find all the cracks and gaps in your house, and the settling of the house and other stresses may create more cracks as time passes. Also, the openings in the top row of concrete blocks in a wall are often inaccessible or otherwise difficult to seal tightly. As a house settles and reacts to external and internal stresses, old seals can deteriorate and new cracks can appear. Therefore, periodic checking and maintenance are required.

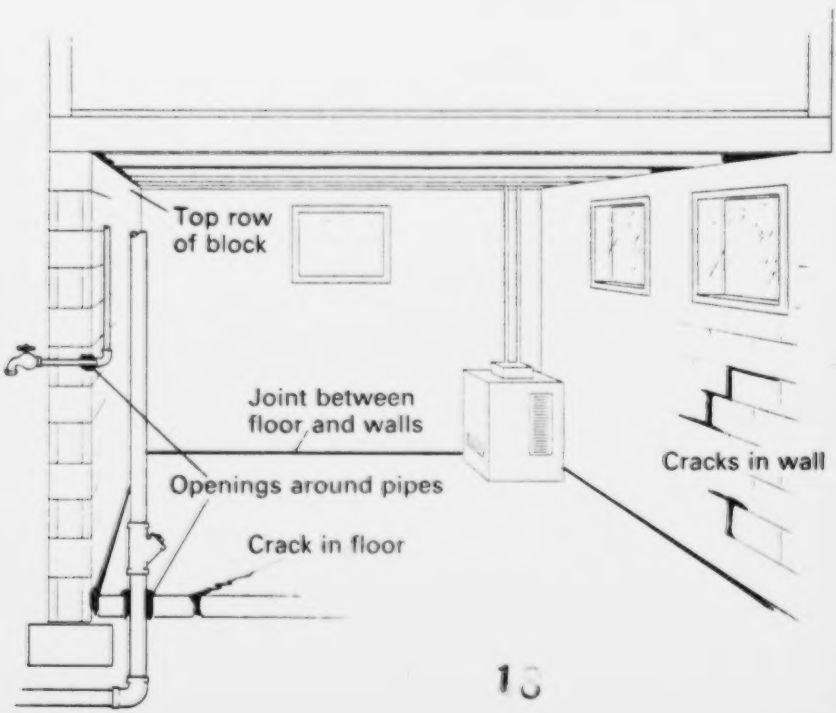
Procedure

If possible, the holes in the top row of concrete blocks in the basement walls should be sealed with mortar or urethane foam.

Seal wall and floor joints with polyurethane membrane sealants and a protective concrete cap.

Cracks and utility openings should be enlarged enough to allow filling with compatible, gas-proof, non-shrinking sealants.

Porous walls (especially block walls) require the application of waterproof paint, cement, or epoxy to a carefully prepared surface.

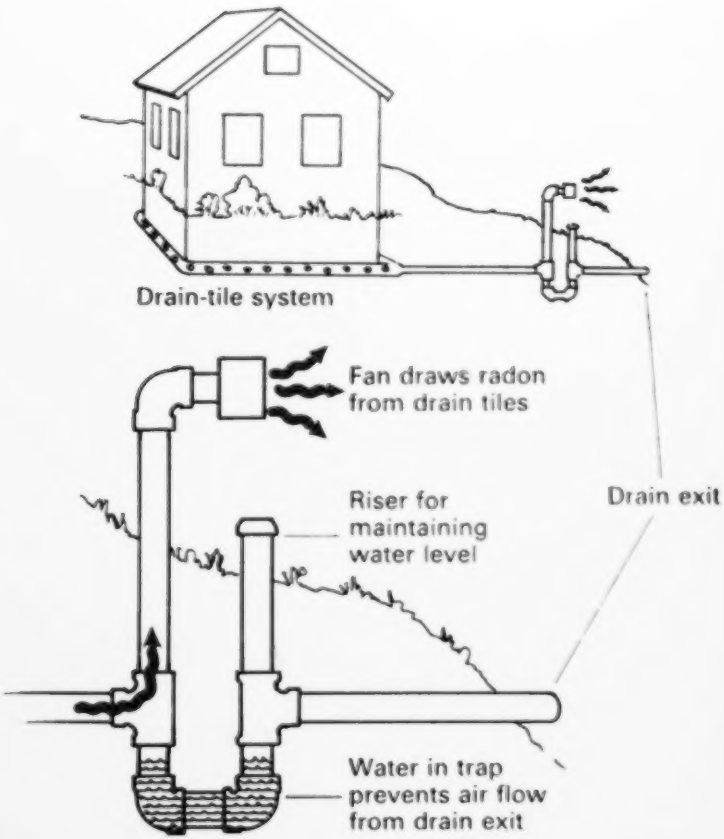


Method	Drain-Tile Suction
How It Works	Water is drained away from the foundation of some houses by perforated pipes called drain tiles. If these drain tiles form a continuous loop around the house, they may be used to pull radon from the surrounding soil and vent it away from the house.
Installation	Normally requires installation and testing by competent, experienced professionals.
Cost	Installation costs (labor and materials) could be approximately $1200. The fan, trap, and riser probably could be added to an existing drain-tile system for around $100. Annual operating costs would typically be $140 or less.
Reductions	In some houses, the installation of a drain-tile suction system could result in radon reductions as great as 98 percent.
Limitations	This method is applicable only to houses having drain tiles which are connected in a continuous loop around the entire house and are not closed at any point by silt or other debris. (Sometimes, minor blockage can be overcome by a more powerful fan.) Drain-tile suction will usually not work effectively if there are block walls dividing the interior of your basement. This method is unlikely to provide sufficient reductions of radon levels that are above 1.0 WL (200 pCi/l).

Procedure

Water collected by drain tiles normally flows through a pipe to a drainage area away from the house or into a sump. Radon can be pulled from the soil beneath a house by attaching an exhaust fan to the collection pipe or to the sealed sump.

To prevent outside air from being drawn from the end of the collection pipe, a water-filled trap should be installed in the pipe beyond the point where the fan is attached. This trap (similar to the trap beneath a kitchen sink) must be placed below the freeze line.


Drain-tile system
Fan draws radon from drain tiles
Drain exit
Riser for maintaining water level
Water in trap prevents air flow from drain exit

Method	**Block-Wall Ventilation**
	Draws radon from the spaces within concrete block walls before it can enter the house ("wall suction") or blows into block walls so that radon is prevented from entering the walls ("wall pressurization").
How It Works	Draws radon from the spaces within concrete block walls before it can enter the house. The concrete blocks used to construct many basement walls contain hollow spaces which are connected both horizontally and vertically. Radon from the soil—which enters the wall through joints or tiny pores and cracks—can travel through these connected spaces and enter the basement through similar openings on the interior side or through the openings in the top row of block.
Installation	Requires installation and testing by competent, experienced professionals.
Cost	The installation of a series of exhaust pipes in an unfinished basement would cost about $2500. A baseboard collection system in a similar basement would cost about $5000 to install. Operating costs would typically be $140 or less per year.
Reductions	In some homes, the operation of a wall ventilation system can reduce radon levels by as much as 99 percent or more.
Limitations	Applicable only to houses with hollow block basement walls. Block-wall suction may not be successful if you cannot seal the top of the walls, the space between the walls and any exterior brick veneer, and openings that could be concealed by masonry fireplaces or chimneys, in addition to sealing noticeable cracks and openings. If you cannot, so much air may leak into the walls that the fan will be unable to maintain suction. In this case, reversing the system and using wall pressurization may be a better approach. Block walls dividing the interior of a basement sometimes penetrate the floor and touch the underlying soil. Exhaust pipes must be installed in all such walls. Although this method can be used for any radon level, it is best suited to levels above 0.2 WL (40 pCi/l).

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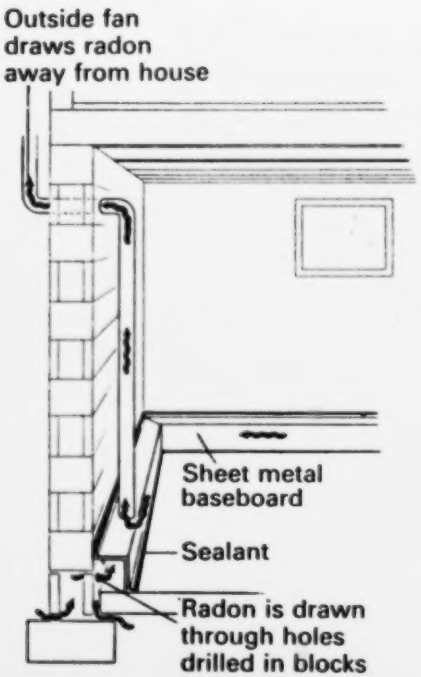
Procedure

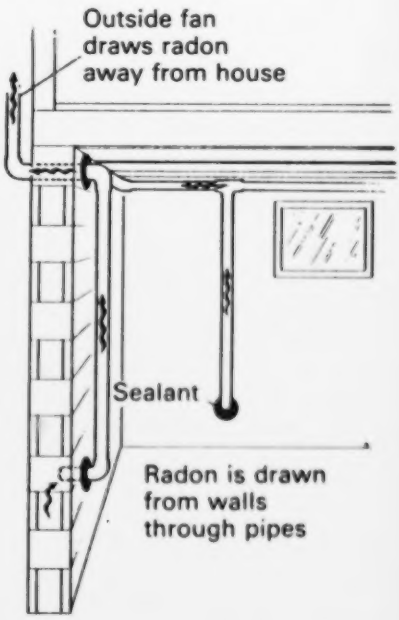
There are two basic approaches to block-wall ventilation. The easiest way is to insert one or two pipes into each wall and use fans to draw radon out of the walls and vent it outdoors, or use fans to pressurize the walls to prevent radon entry. The other approach involves the installation of a sheet metal "baseboard" duct around the perimeter of the basement. Holes are drilled behind the ducts into the hollow spaces within the blocks. This second approach produces more uniform ventilation, and may be more pleasing in appearance.

In houses which have channel drains cast in the concrete floor under the block walls, the baseboard approach should work particularly well, since it would ventilate the drains as well as the walls.

For either wall-ventilation approach to work, all major holes must be sealed. As we pointed out previously, this might be difficult—if not impossible—to do in certain places. (Both of the approaches are shown below in the "suction" mode.)



Baseboard Approach

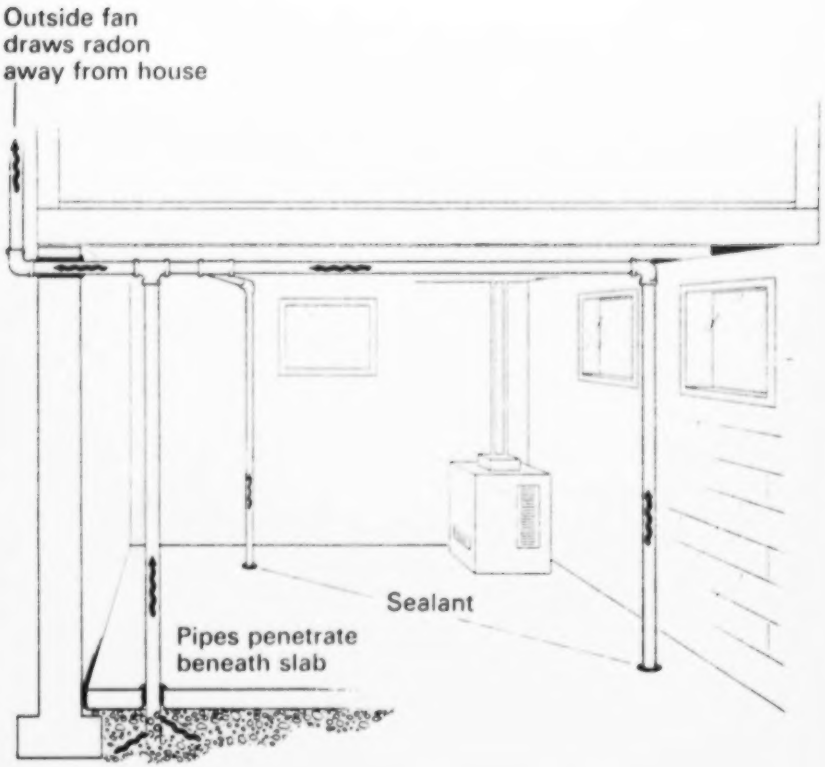


Pipe-In-Wall Approach

Method	**Sub-Slab Suction**
How It Works	The lowest floor of most houses, other than those built over crawl spaces, consists of a concrete slab poured over the earth or on top of crushed rock (aggregate). Radon which accumulates under the slab can be drawn out and vented away from the house.
Installation	Requires installation and testing by competent, experienced professionals.
Cost	Installation costs for a multiple-pipe through-the-slab system would be about $1000 to $2000. Annual operating costs would typically be $140 or less.
Reductions	Installation of a sub-slab suction system can reduce indoor radon levels by 80 to 90 percent. In some cases, 99 percent reductions have been achieved.
Limitations	Sub-slab suction is most useful with foundations built on good aggregate or on highly permeable soil. In some cases, it may be difficult to create enough suction to prevent radon from penetrating hollow-block basement walls. In these cases, major openings in the walls—including the holes in the top row of blocks—should be sealed. If this is not sufficient, more pipes may have to be inserted in the slab, or a wall-ventilation system may have to be added. The sub-slab suction method is probably not suitable for houses with radon levels above 2.0 WL (400 pCi/l).

Procedure

The most common approach is to drill holes (two may be enough) through the slab and insert pipes which are connected to an outside fan. The holes around the pipes must be tightly sealed.



Comparison of Features

Method	Installation Cost	Operating Cost	Maximum Possible Reductions*
Natural ventilation:			
Basement or lowest floor	Minimal	Very high	Up to 90 %
Crawl space	Minimal	Moderate	Up to 90 %
Forced ventilation:			
Basement or lowest floor	Low	Very high	Up to 90 %
Crawl space	Low	Moderate	Up to 90 %
Air supply	Low to moderate	Low	Site specific
Heat recovery ventilation	Moderate to high	Moderate	Up to 90 + %
Covering exposed earth	Moderate	Low	Site specific
Sealing cracks and spaces	Minimal to moderate	None	Site specific
Drain-tile suction	Moderate to high	Low	Up to 97 + %
Block-wall ventilation	High to very high	Low	Up to 97 + %
Sub-slab suction	High to very high	Low	Up to 97 + %

* **These represent the best reductions that a single method can accomplish. You may get higher or lower reductions depending on the unique characteristics of your house. It is likely that reductions in your house wil not be as great as those shown. Especially with high initial radon levels, several methods may have to be combined to achieve acceptable results.**

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Comment

Useful, immediate step to reduce high radon levels.

More controlled than natural ventilation.

May be required to make other methods work.

Air intake and exhaust must be equal.

Required to make most other methods work.

Required to make most other methods work.

Works best when drain tiles are continuous, unblocked loop.

Applies to block-wall basements. Sub-slab suction may be needed to supplement.

Important to have good aggregate or highly permeable soil under slab.

Sources of Information

If you would like further information or explanation on any of the points mentioned in this booklet, you should contact your state radiation protection office.

If you have difficulty locating this office, you may call your EPA regional office listed below. They will be happy to provide you with the name, address, and telephone number for your appropriate state contact.

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